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Spitzer IRS spectra of Luminous 8 μm Sources in the Large Magellanic Cloud

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Abstract. We have produced an atlas of Spitzer Infrared Spectrograph (IRS) spectra of mass-losing, evolved stars in the Large Magellanic Cloud. These stars were selected to have high mass-loss rates and so contribute significantly to the return of processed materials to the ISM. Our high-quality spectra enable the determination of the chemistry of the circumstellar envelope from the mid-IR spectral features and continuum. We have classified the spectral types of the stars and show that the spectral types separate clearly in infrared color-color diagrams constructed from 2MASS data and synthetic IRAC/MIPS fluxes derived from our IRS spectra. We present diagnostics to identify and classify evolved stars in nearby galaxies with high confidence levels using Spitzer and 2MASS photometry. Comparison of the spectral classes determined using IRS data with the IR types assigned based on NIR colors also revealed a significant number of misclassifications and enabled us to refine the NIR color criteria resulting in more accurate NIR color classifications of dust-enshrouded objects.

1. Introduction

Asymptotic Giant Branch (AGB) stars dominate the return of processed materials to the interstellar medium (ISM) and therefore are an important component of galaxy evolution. High mass-loss rate objects are heavily obscured, so they can be missed in optical surveys and need to be observed in the infrared (IR). We have conducted a study using the *Spitzer Space Telescope* InfraRed Spectrograph (IRS; Houck et al. 2004) of a sample of luminous 8 μm sources in the Large Magellanic Cloud (LMC). Our sample was selected from a compilation of *2MASS/MSX* sources (Egan et al. 2001), using near-infrared color and magnitude criteria to target high mass-loss, evolved objects.

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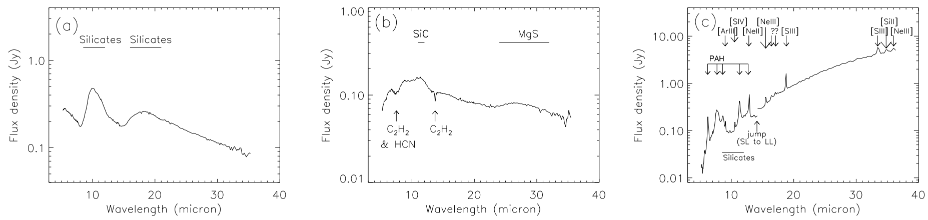

Figure 1. *(a)* IRS spectrum of a typical O-rich object (MSX LMC 264), showing broad silicate emission features at 10 and 18 μm. *(b)* Typical spectrum of a C-rich object (MSX LMC 1400), showing broad SiC dust emission at 11.3 μm, and narrow C_2H_2 gas absorption at $\sim$7.5 and 13.7 μm. *(c)* Typical spectrum of an emission-line object (MSX LMC 22), showing narrow forbidden emission lines, broad PAH emission features, and red continuum indicative of cool dust.

IRS low-resolution spectra of 62 targets were obtained in Cycle 1. An atlas of the spectra has been presented in Buchanan et al. (2006). The spectra reveal continuum and spectral features that allow the dominant chemistry of the dust circumstellar envelope to be determined. Figure 1 shows typical spectra of Oxygen-rich (O-rich), Carbon-rich (C-rich), and emission-line objects.

2. Results: Classification of IR-luminous Objects

We find that almost all the O-rich stars are red supergiants (RSGs) with infrared luminosities $L_{IR} > 5 \times 10^4$ $L_\odot$ (Figure 2). The lack of lower luminosity O-rich AGB stars suggests that massive supergiants do not have long enough He-burning lifetimes to produce C-rich surfaces (and hence C-rich ejecta), despite the low metallicity of the LMC. The C-rich stars are all AGB stars with $L_{IR} < 5 \times 10^4$ $L_\odot$. The large number of C-rich AGB stars stands in stark contrast to the lack of O-rich AGB stars found. This result is consistent with the hypothesis that C-rich stars form more easily than O-rich ones due to the low metallicity environment of the LMC. We find that the emission-line objects are all H II regions with $L_{IR} > 10^4$ $L_\odot$. These objects were all expected to be Planetary Nebulae (PNe) based on *2MASS/MSX* colors (Egan et al. 2001), but optical and IR images reveal diffuse nebulae around the objects, and the IRS spectra show a jump in flux density between the Short-Low (5.2 – 14 μm, slit width 3.6″) and Long-Low (14.0 – 38 μm, slit width 10.5″) modules indicating the emission is extended on parsec scales. The spectra also show a lack of high-ionization narrow emission lines common in PNe (e.g., Kraemer et al. 2002; Bernard-Salas et al. 2004).

3. Diagnostics: Photometric Classifications

Photometric tools such as color-color diagrams are invaluable for identifying and classifying stellar objects. However, photometric diagnostics must first be reliably associated with spectral properties using spectroscopy. We used our IRS spectra to revise the *2MASS/MSX* classification criteria of Egan et al. (2001).

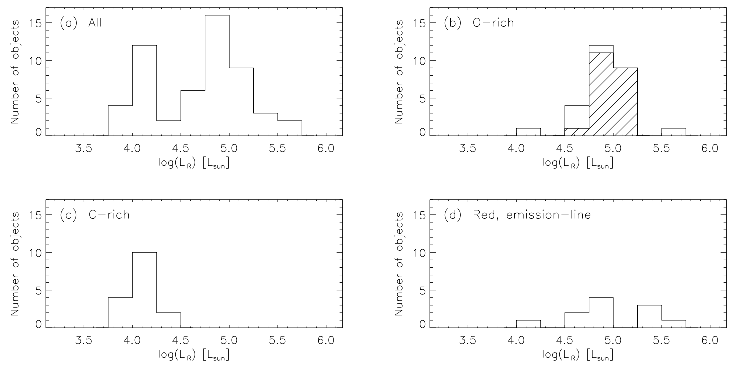

Figure 2. Histograms showing the distributions of the IR luminosity for *(a)* the whole sample, *(b)* the O-rich stars, *(c)* the C-rich stars, and *(d)* the PAH-rich objects separately. The hatched regions of the histogram for O-rich objects indicate stars classified as RSGs based on their IR luminosities. The highest luminosity O-rich star that is not an RSG is an OH/IR supergiant.

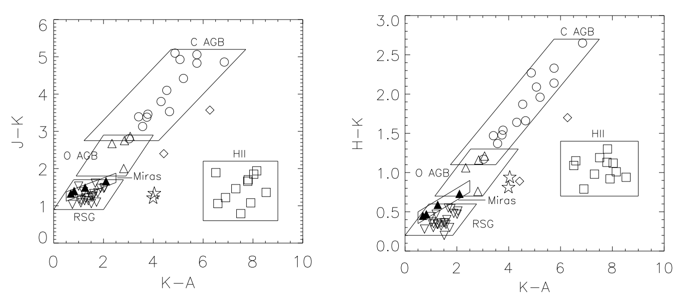

Figure 3. *2MASS/MSX* color-color diagrams. The symbols indicate the IRS spectral type: RSGs *(open, inverted triangles)*, O-rich AGB stars *(open triangles)*, Galactic Mira variables *(filled triangles)*, C-rich AGB stars *(open circles)*, H II regions *(open squares)*, B[e] supergiants (Kastner et al. 2006; *open stars*), and OH/IR stars *(open diamonds)*. The boxes indicate the new NIR color criteria to classify IR-luminous LMC objects.

In Figure 3 we present *2MASS/MSX* color-color diagrams showing our improved photometric classification criteria.

One of the primary goals of our *Spitzer* program was to provide a spectroscopic basis for IRAC and MIPS photometric classifications of IR sources in external galaxies. To that end, we derived synthetic IRAC and MIPS magnitudes using the IRS spectra and the imaging filter spectral response functions. Figure 4 shows the resulting color-color diagrams and diagnostics for identifying spectroscopic classes.

4. Summary and Conclusions

We have obtained low-resolution IRS spectra of a sample of 60 luminous 8 μm sources in the LMC and classified the sources according to their spectral properties. Almost all of the AGB stars in the sample are C-rich, while the O-rich

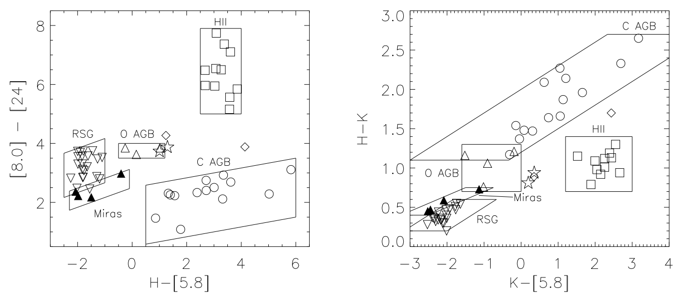

Figure 4. Synthetic *Spitzer/2MASS* color-color diagrams, showing our proposed criteria for classifying object types. Symbols are the same as Figure 3.

objects are luminous RSGs. We use our spectroscopic classifications to develop revised infrared photometric diagnostics to classify luminous IR sources, thus correcting inaccuracies in current widely-used criteria. We propose new photometric diagnostics to identify IR sources in other galaxies, based on synthetic *Spitzer* photometry and existing *2MASS/MSX* photometry. A full discussion of the data analysis and additional results will appear in Buchanan et al. (2006).

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